

Recent Upgrades of the Optical Synchronization System at FLASH

FEL Seminar

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Hamburg, 5. February 2019

Outline

01 Introduction

- laser-based synchronization at DESY
- FLASH: Why upgrading the LbSync system?

02 Optical Reference & Distribution

- overview
- master laser oscillator
- synchronization laboratory
- fiber link stabilization
- MicroTCA.4

03 End Stations

- laser-to-RF phase detection and RF re-synchronization
- laser synchronization
- (BAM)

04 FLASH Upgrades 2018+

- overall timeline
- upgrades 2018
- status & next steps

05 Summary

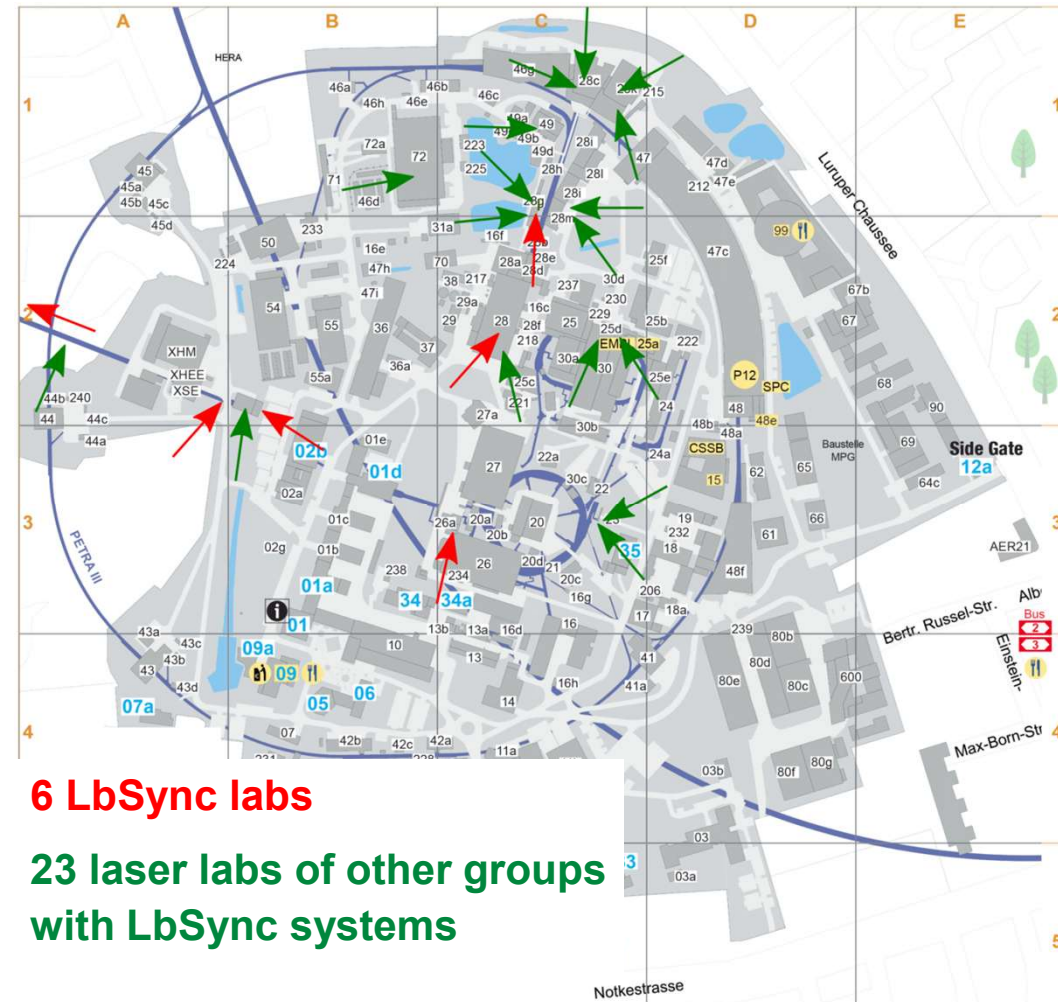
Introduction

LbSync Activities at DESY

Group Structure and Historical Overview

LbSync team: currently 7 members

- 2004: first developments started in collaboration with MIT, hosted in FLA group,
- **2008: LbSync operation at FLASH started**
- 2010: project moved to MSK
- 2017: first experiments at XFEL using optical synchronization
- **2018: renewal of FLASH LbSync system**
- 2018: SINBAD injector laser synchronization
- 2019: finish installation of XFEL LbSync system
- **2020: finish renewal of FLASH LbSync system**
- 2020+: installation LbSync at SINBAD



FLASH Optical Synchronization Upgrades 2018+

Why Upgrading?

Performance

- MZI-based MLO synchronization: **jitter 30 fs** → **3 fs, drift stability**
- single-mode fiber (SMF) replaced by polarization-maintaining (PMF)
 - **jitter 3 fs** → **0.5 fs**
 - enhanced drift stability
- MicroTCA.4-based system
- laser synchronization: **jitter 15 fs** → **5 fs**

Space

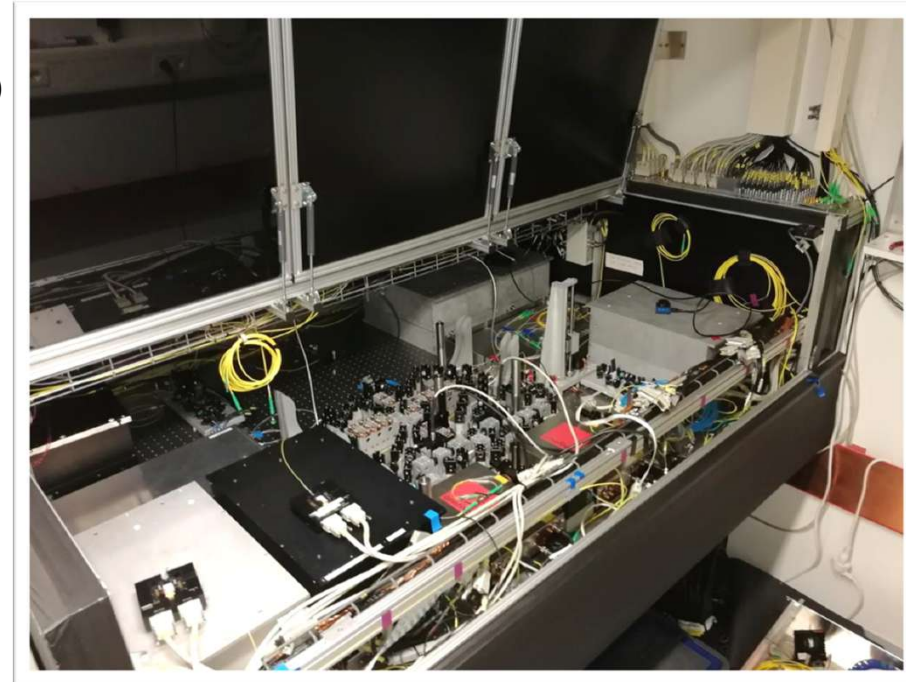
- old structure (optical table, infrastructure, etc) allowed **only 8 links**
- **24 optical links required** including potential future upgrades

Discontinued Components

- VME system
- migration of all control electronics to MicroTCA.4

Reliability & Maintainability

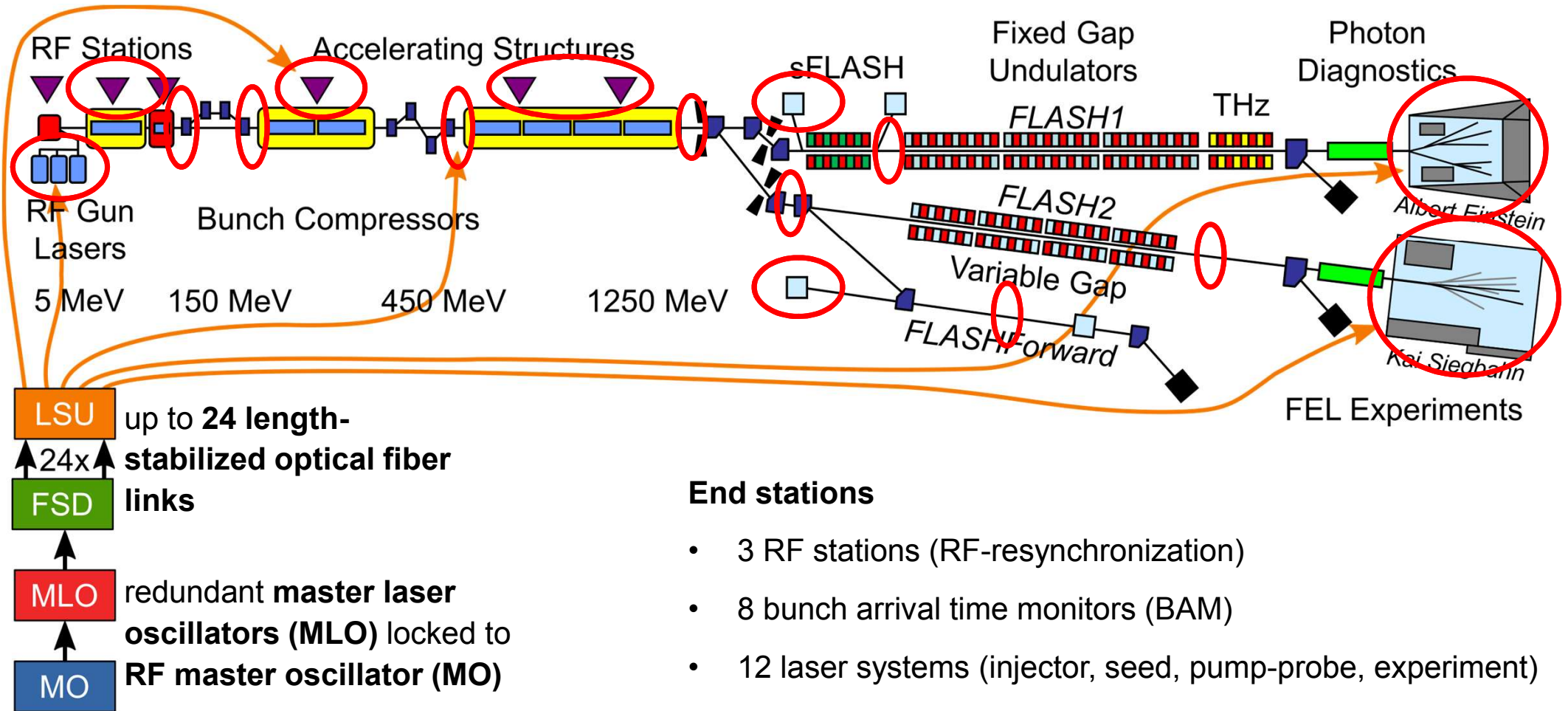
- same setup like at the XFEL
- software / firmware



Optical Reference & Distribution

FLASH Optical Synchronization System

System Overview



Main Synchronization Laboratory XFEL

Infrastructure

- strict separation of optics, electronics, general working space
- **no electronics in optics part** → no heat sources, EMI, vibration
- environmental stability → $dT < 0.1K$ / $dRH < 5\%$
- EMI → **proper grounding** (single grounding point), optical cables used if possible, separate potential EMI sources from critical systems
- acoustics & vibrations → **optics part acoustically isolated**
- UPS for operation-critical systems



main optical table at XFEL, UG5

Master Laser Oscillator (MLO)

The Main Optical Reference

Oscillator

- commercial (NKT, former Onefive)
- SESAM-based, passively mode-locked
- ultra-low phase noise, Erbium, 1550 nm
- 24/7 operation

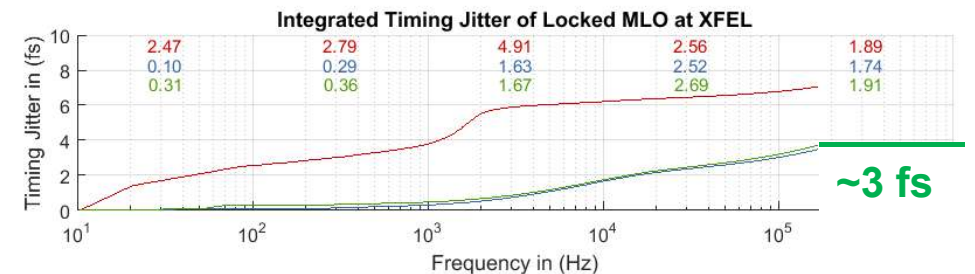
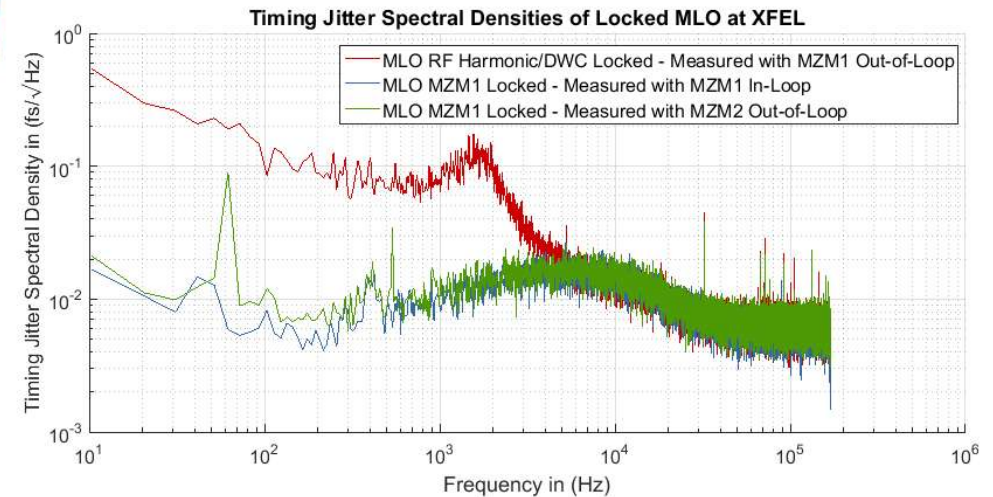


Synchronization

- laser-to-RF based, **low-noise (~3 fs)**, low-drift, amplitude insensitive locking scheme

Redundancy

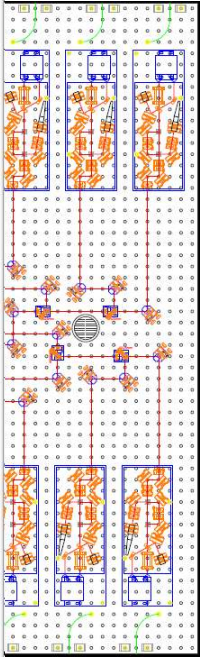
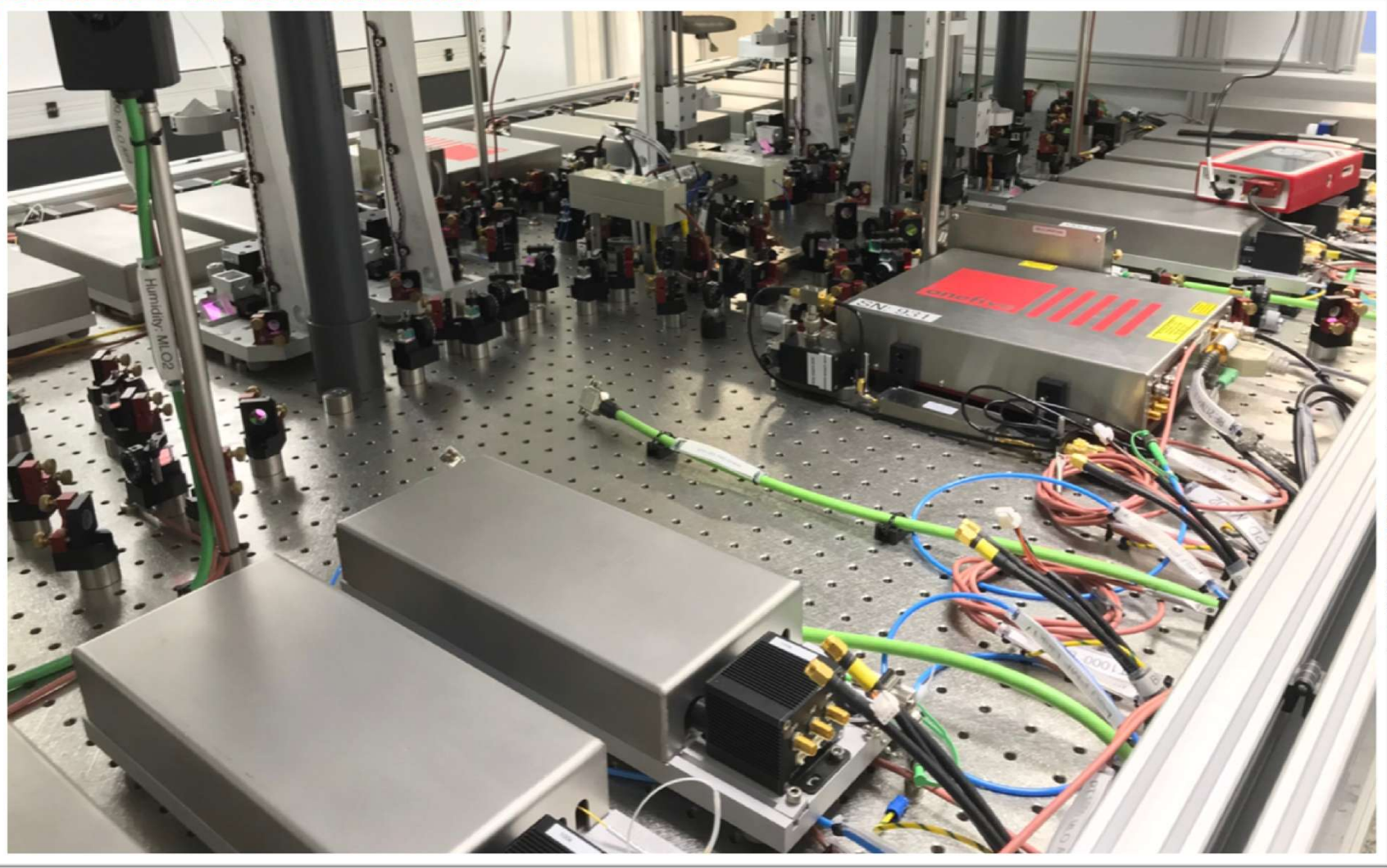
- two similar laser oscillators
- both synchronized all the time, individual setups, identical timing
- fast switching of active source: no link lock lost, timing preserved



Free-Space Distribution

Laser Beam

- Superlattice
- thermally stable
- no bias
- second order
- space frequency
- identical
- 8 link system
- arbitrary
- table controlled
- stable
- $\ll 0.1$
- online
- (air, table)



CAD drawing courtesy of C. Sydlo

LSU: Principle of Operation

Measurement

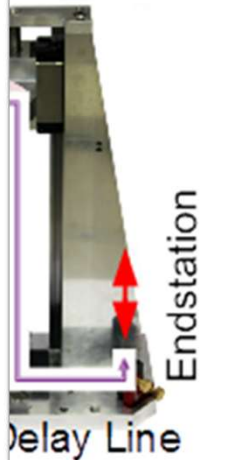
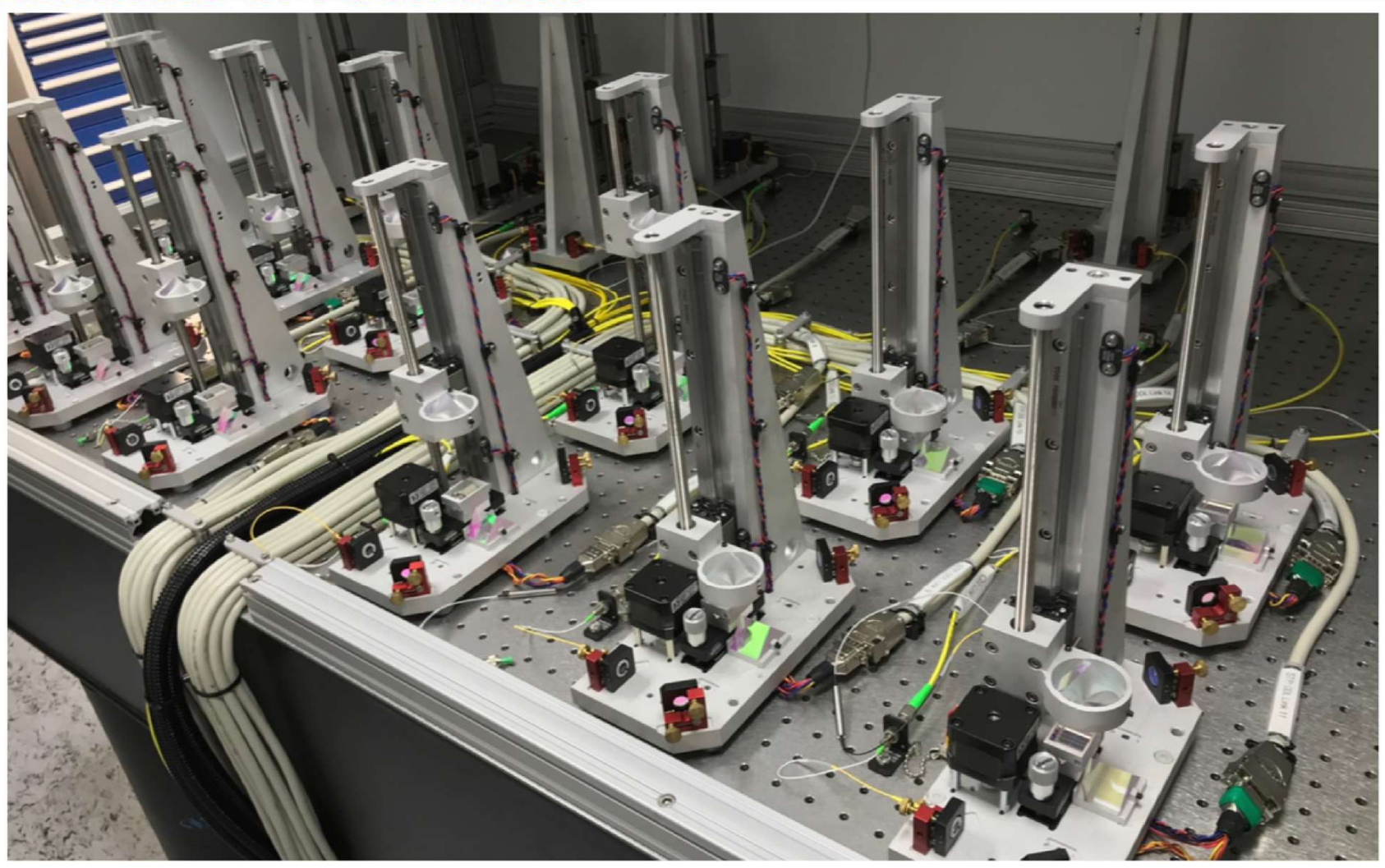
- balance
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- typic
- **polariz**
- related

Detection

- self-bui
- (0.1 mV
- **MTCA**
- and mo

Actuators

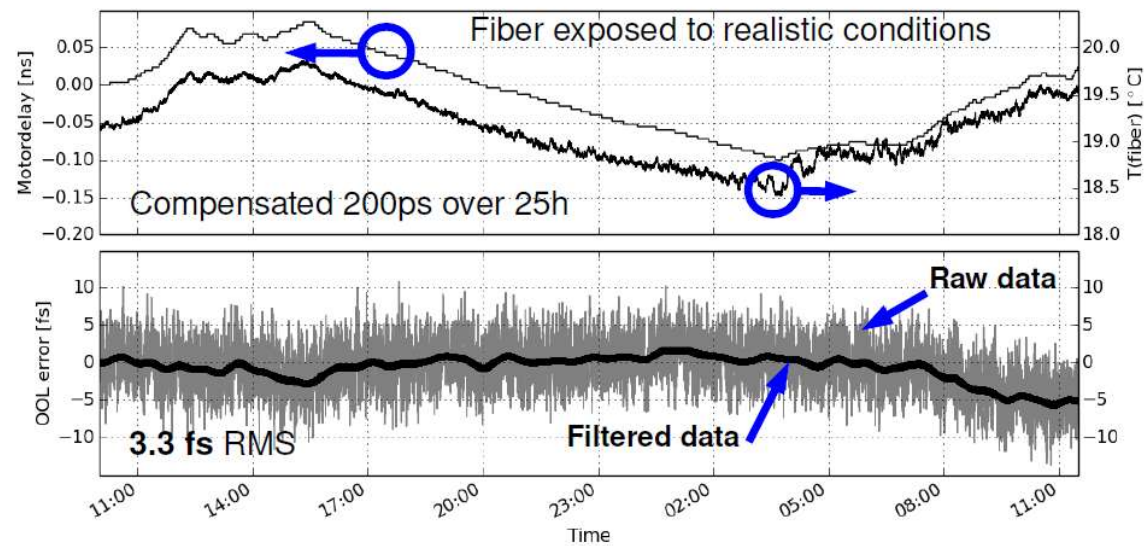
- piezo
- optic



Link Stabilization Units (LSU)

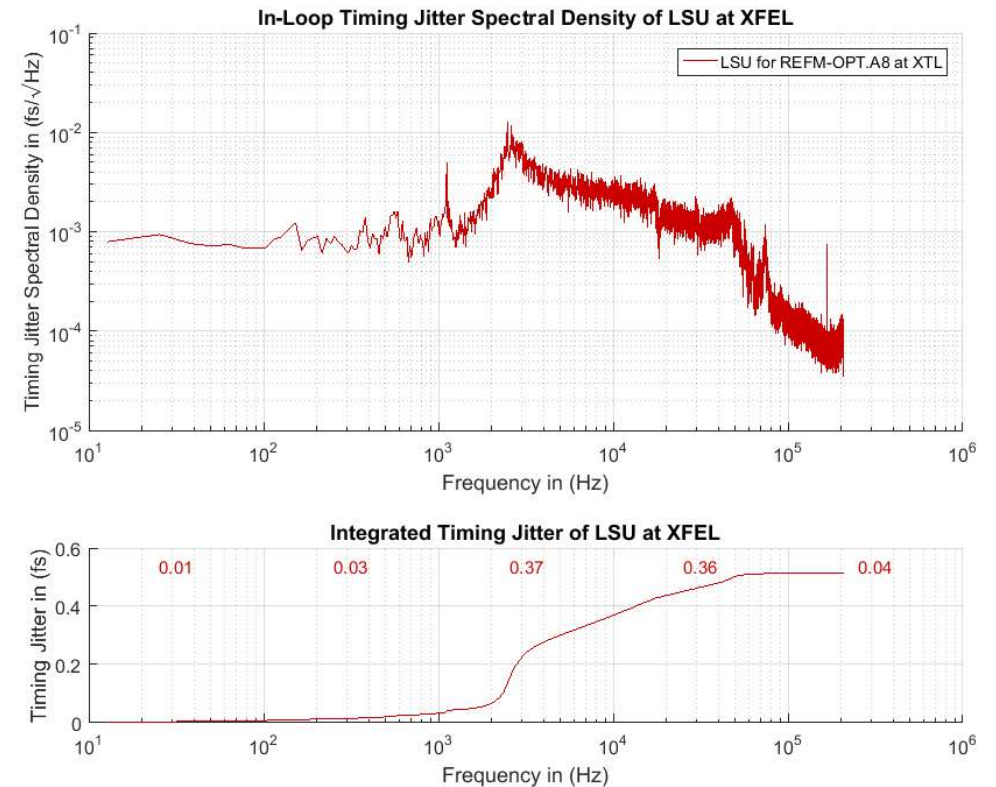
Measurement Results

Link-Stabilization-Units: Out-of-loop measurement



Performance

- jitter (rms) < 500 as
- drift: 3.3 fs / 24 h
- observed drift compensation at XFEL: **up to 200 ps/km!**



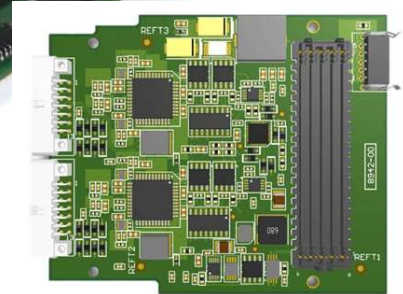
MicroTCA.4

MicroTCA.4 for LbSync

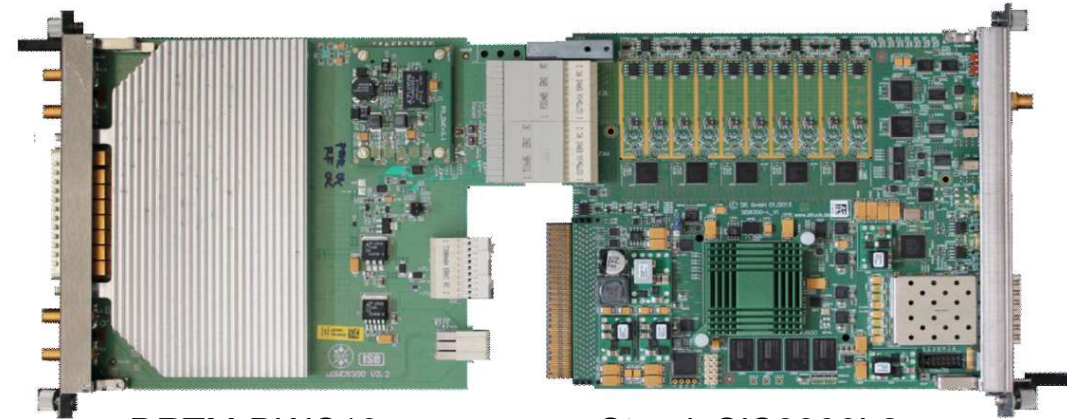
- **DRTM-DWC10**: 10 channel RF down-converter for laser synchronization
- **DRTM-LASY**: dedicated laser synchronization board
- **DRTM-AD84**: ADC board for link signal detection
- **DRTM-PZT4**: 4-Ch, $\pm 100V$ piezo driver for link & laser synchronization
- **DAMC-FMC20**: FMC carrier board laser synchronization
- **DAMC-FMC25**: FMC carrier / FPGA link synchronization
- **SIS8300L2**: 10-Ch 125 MS/s 16-bit ADC, 2x 16-bit DACs, Virtex FPGA
- **DFMC-MD22**: 2-Ch, encoder
- **DFMC-UNIIO**: universal I/O, MLO/shutter control
- **DFMC-AD16**
- **X2TIMER**



DAMC-FMC20



DFMC-MD22



DRTM-DWC10

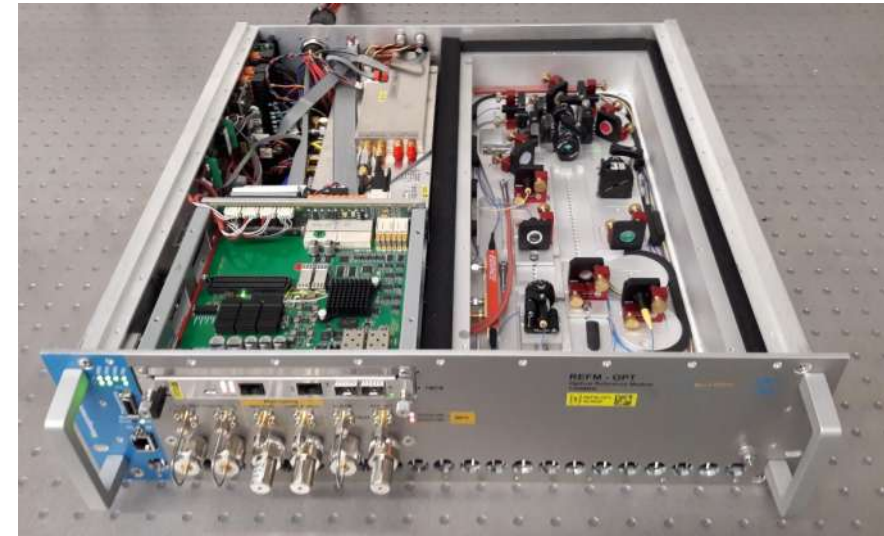
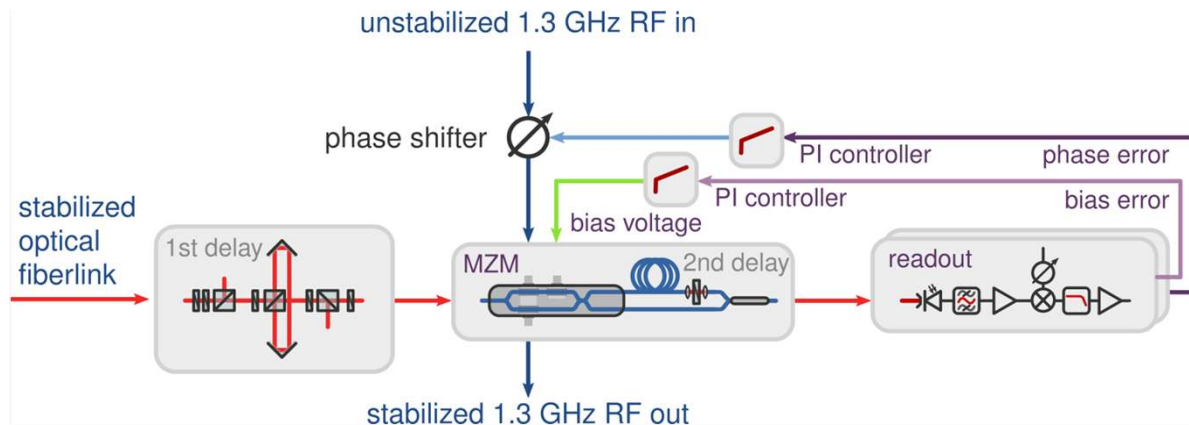
Struck SIS8300L2

End Stations

The Optical Reference Module (Refm-Opt)

Femtosecond RF Reference Phase Stabilization

- uses a stabilized fiberlink from the pulsed optical synchronization system as reference
- employs a **drift-free L2RF phase detector**
- locally **re-synchronizes the 1.3 GHz** RF reference with femtosecond precision in a PLL
- phase-stabilized Wilkinson splitter to provide multiple outputs



Engineering

- fully integrated stand-alone 19" module
- temperature and humidity stabilized optical compartment

Laser Synchronization

Laser Synchronization Schemes – Comparison

RF

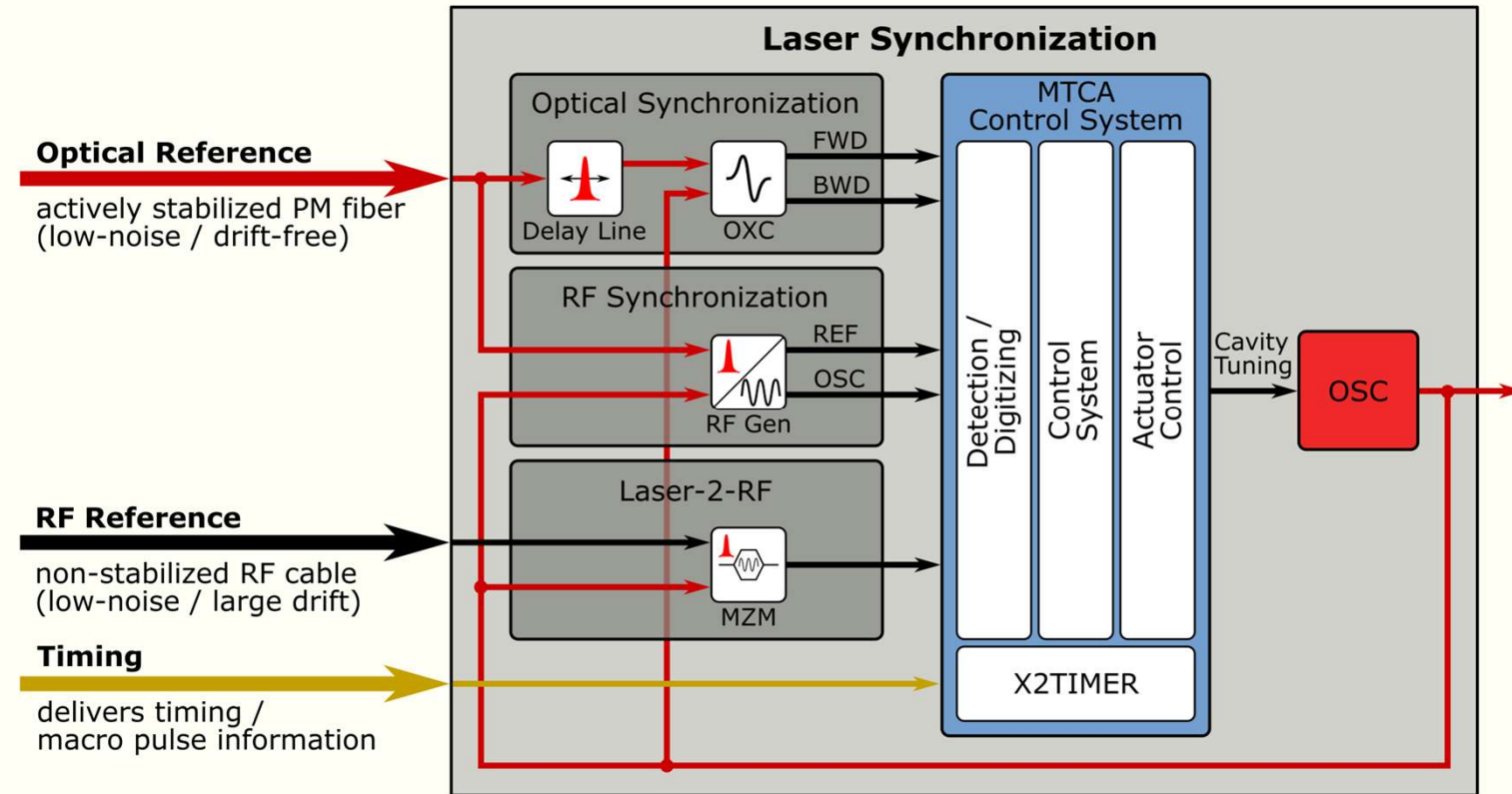
- easy to implement
- low-jitter (<20 fs)
- large drift (hundreds of fs), AM-to-PM

Laser-to-RF

- low-jitter (~3 fs)
- low-drift (<10 fs)
- requires high-power budget
- implementation challenging

Laser-to-Laser

- ultra low-jitter (<1 fs)
- low-drift (<10 fs)
- implementation challenging



Laser Synchronization – RF-based

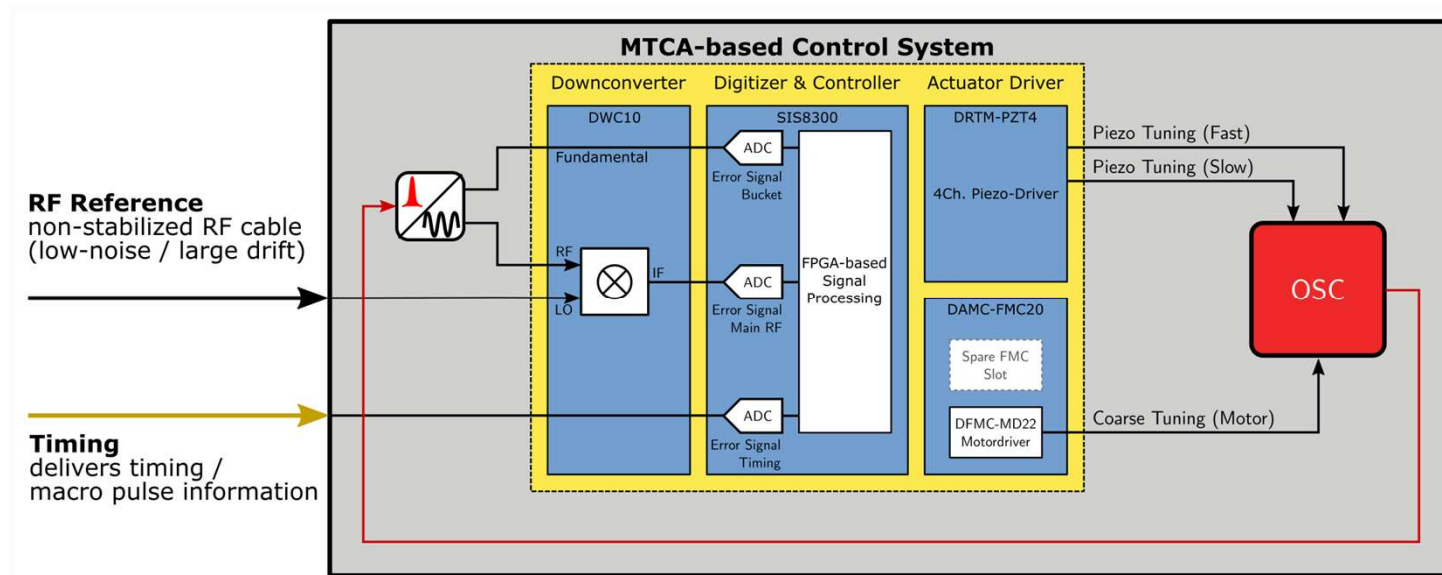
Based on Conventional RF Synchronization Scheme

Concept

- RF mixing scheme: reference at 1.3 GHz mixed with $1.3 \text{ GHz} + f_{\text{rep}}$
- IF signal at f_{rep} is digitized by fast ADCs (clock derived from reference) and evaluated regarding magnitude/phase
- no DC error signal
 - locking to arbitrary phase set point possible
 - less EMI-related distortions
 - no DC-offset drifts
 - better $1/f$ noise performance

MicroTCA.4-based controls

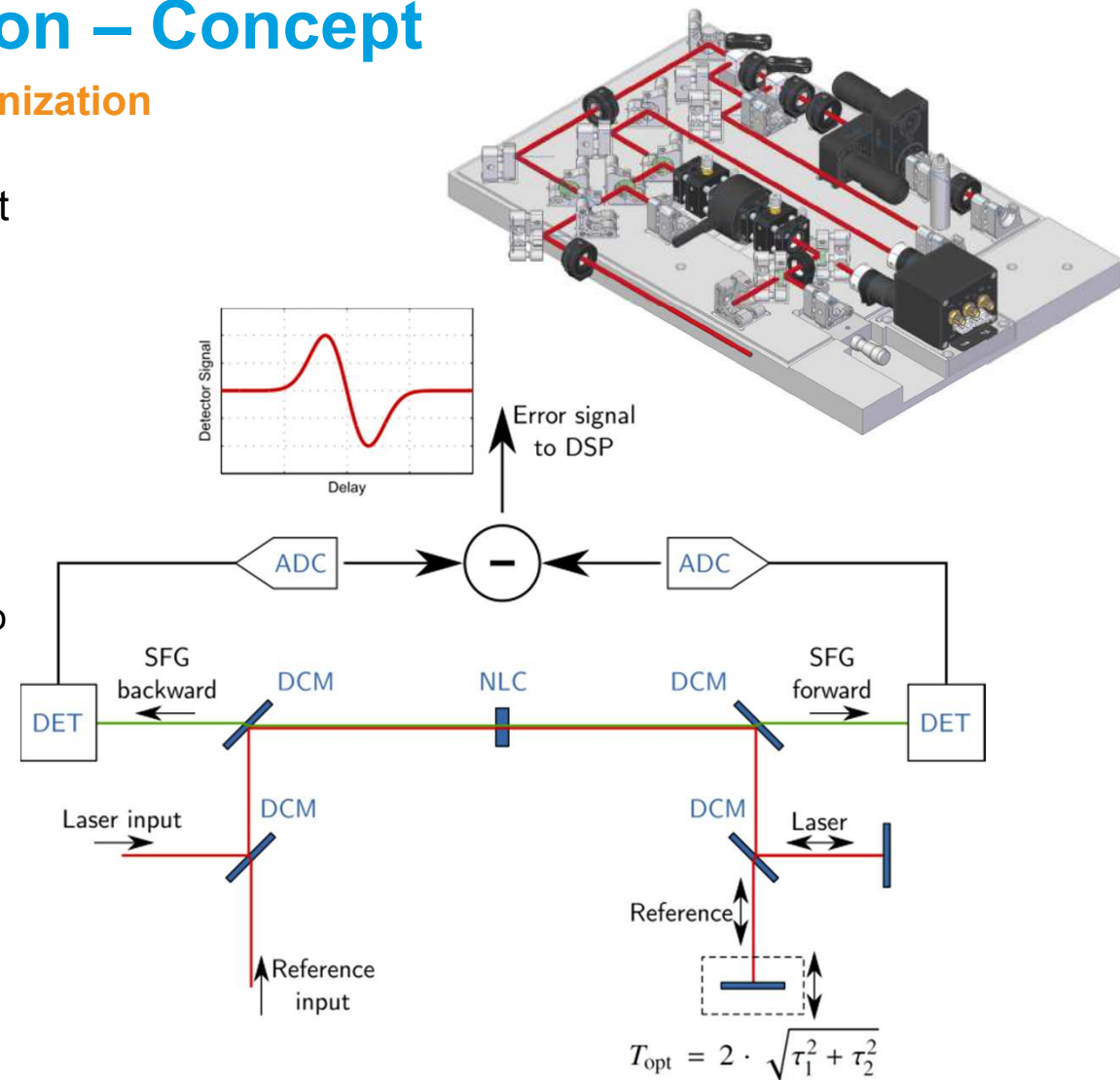
- variety of oscillator configurations supported (1 or 2 piezos, motor/piezo stage/temperature tuning, ...)
- dedicated laser sync RTM under development



Laser-to-Laser Synchronization – Concept

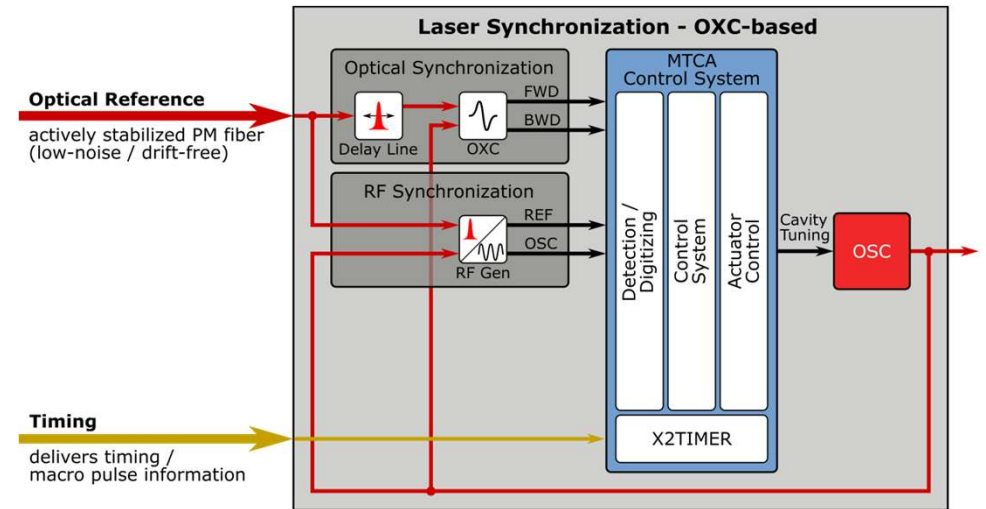
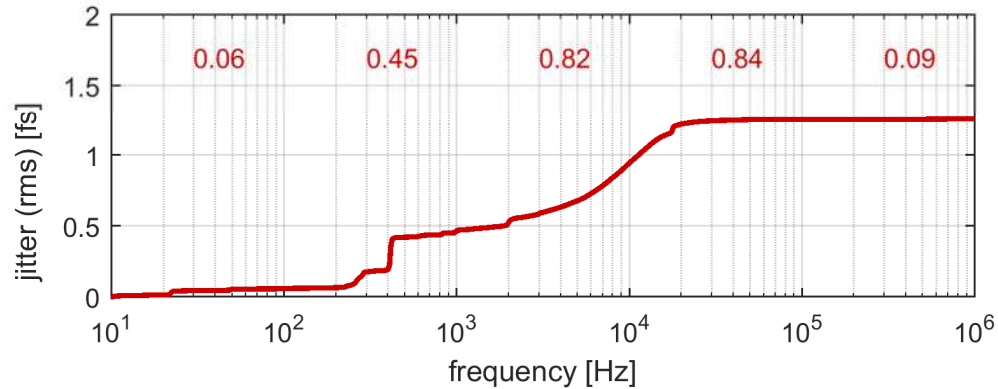
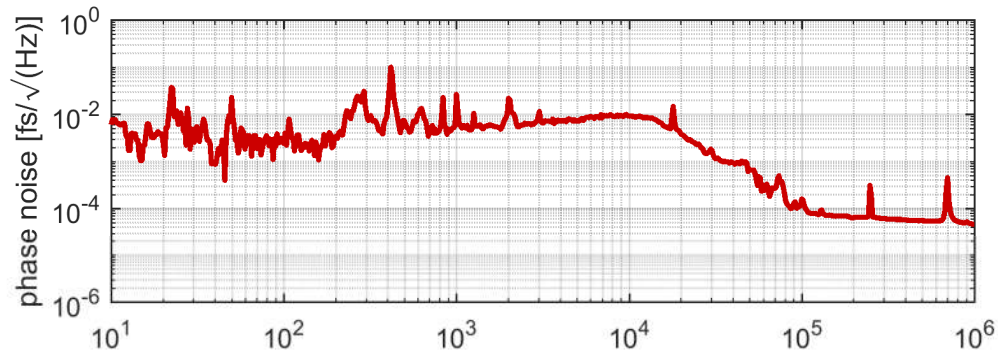
Ultra-low Jitter, drift-free Laser-to-Laser Synchronization

- **all-optical scheme** for timing error measurement
 - high accuracy: <100as/mV
 - pure phase-sensitive measurement
 - no drifts due to RF cables etc
- based on **two-color balanced optical cross-correlation**
 - aim: precisely measure the timing error between two pulsed laser sources
 - twofold sum-frequency generation in a non-linear crystal (BBO/PPKTP/PPLN)
 - differential scheme eliminates AM-related influence on the phase measurement
- one **common design** covering requirements of different laser systems



Laser-to-Laser Synchronization

Performance



- laser oscillator: Origami-15
- reference via 3.5 km stabilized fiber link
- PPKTP-based OXC
- **1.3 fs rms in-loop jitter [10 Hz..10 MHz]**

FLASH LbSync Upgrades 2018+

FLASH LbSync Upgrades 2018+

Timeline

Phase 1 (summer 2018)

- **complete removal** of old components (optical table, VME electronics, cabling, ...)
- infrastructure installation (new optical table & cover, cabling, rack preparation, MTCA systems, ...)
- **MLO1** laser lock (RF)
- commissioning of **7 optical links**

Phase 2 (summer 2019)

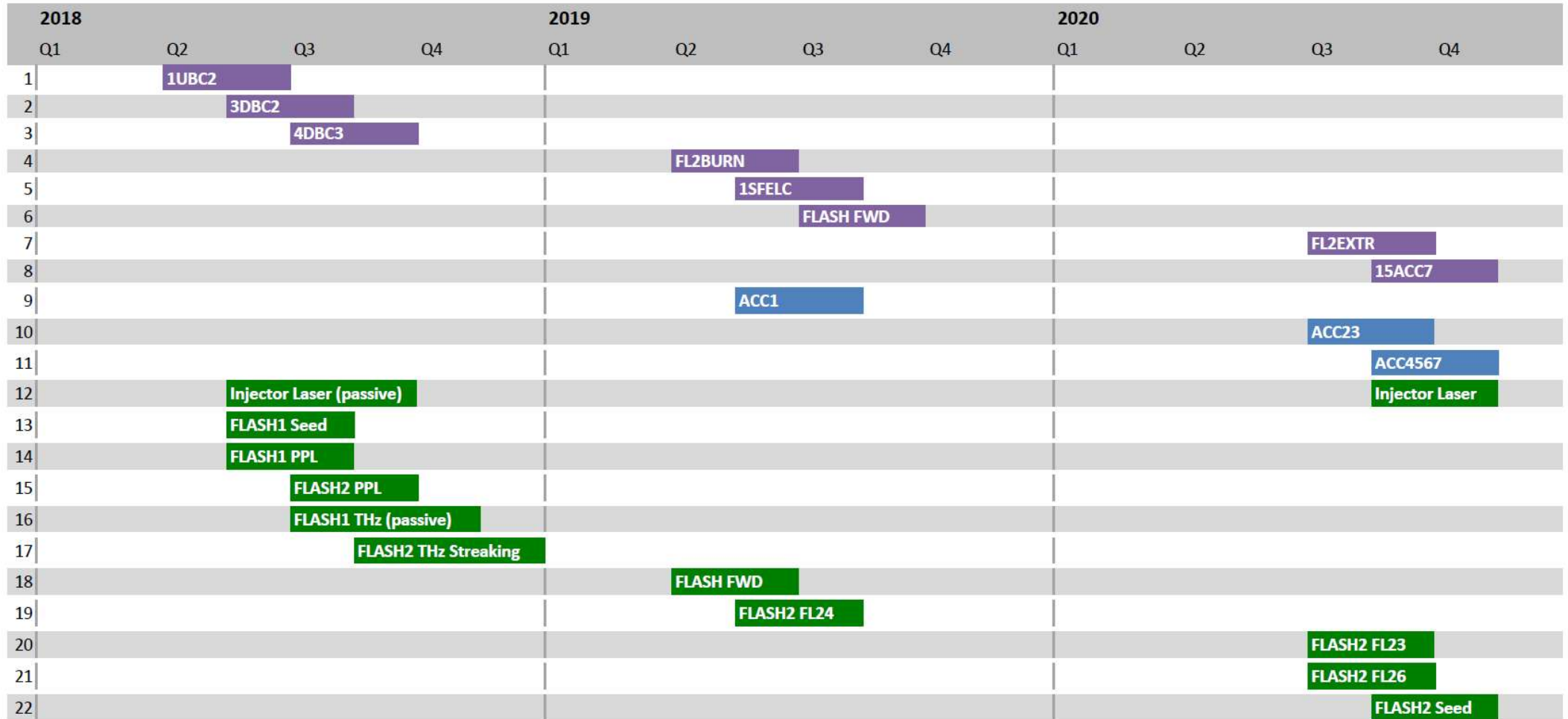
- commissioning of **6 optical links**
- **MLO2** laser lock (RF)

Phase 3 (summer 2020)

- main rack → MO room
- commissioning of **8 optical links**
- **MZM-based** MLO lock

Optical Links at FLASH

Timeline: Link Commissioning



Summer Shutdown 2018

Work in progress...



before...



after 7 weeks of work...

FLASH LbSync Upgrades 2018+

Status & Next Steps

already installed/upgraded

- main distribution system with **infrastructure for 12 LSUs**
- 7 fiber links in operation: **jitter 0.5 fs**
- laser synchronization
 - MLO1 RF-based: **jitter 17 fs**
 - pump-probe laser FLASH1/2: **jitter 5 fs**

next steps

- fiber links
 - 6 additional links 2019
- laser synchronization
 - MLO2 installation – **ongoing**
 - injector laser 1 OXC – **ongoing**
 - FLASH2 THz streaking laser synchronization – **ongoing**
 - PPL: redundant systems for FLASH1 & FLASH2 – Q2/2019
 - exchange remaining VME systems by MTCA .4 (FLASH1 seed, THz beamline) – Q2/2019

DOOCS Controls

Before...

/svn/FLASH/LbSync/LbSync_main.xml //

Laser-Based Synchronisation System

Overview Laser Main LSU Main BAM Main REF-M-L2RF Test Systems

VME Crates & PCs
Sync Crates Version Status

Supervision VME Timing MTCA Crates

No.	Remote Station	FSD LDD	Time Enable	Lock Closed	Link LDD	Jitter (fs)	Compensated Drift (ps)
LSU01	BAM.4DBC3	Green	Green	Green	Green	4.41	1011.156
LSU03	BAM.15ACC7	Red	Red	Red	Red	0.12	1811.429
LSU05	FL1 PP	Green	Red	Red	Red	11.02	522.980
LSU07	FL1 SEED	Green	Red	Red	Red	0.73	732.667
LSU09	BAM.1UBC2	Green	Red	Red	Red	1.37	727.885
LSU11	BAM.3DBC2	Green	Green	Green	Green	2.80	683.134
LSU13	BAM.1SFELC	Green	Green	Green	Green	0.10	934.259
LSU14	FLASH Fwd	Red	Red	Red	Red	0.73	1454.571
LSU15	EOLAB	Red	Red	Red	Red	0.98	714.221
LSU16	REFM_OPT@ACC1	Red	Red	Red	Red	0.10	934.259

Lasers

TD Pilot	DACB	DSP	Tuning	Bucket	RF-Lock	Jitter (fs)
MLO1	TD D8	Green	Green	Green	Green	49.57
MLO2	TD D8	Green	Green	Green	Green	58.92
EO TISA	D8	Red	Red	Red	Red	0.00
Seed	TD D8	Red	Red	Red	Red	0.00
FL1 PPL OSC1		Red	Green	Green	Green	1880...
FL1 PPL OSC2		Red	Red	Red	Red	0.00
THz PPL	TD D8	Red	Red	Red	Red	0.00
FL2 PPL OSC1		Green	Green	Red	Red	36.92
FL2 PPL OSC2		Green	Green	Red	Red	

BAMS

Server: 1UBC2 3DBC2 4DBC3 15ACC7 1SFELC FL2EXTR FL2BURN

Status BAMS: 1UBC2 3DBC2 4DBC3 15ACC7

System Error? Data Valid? M-FB on SLOW-FB FAST BBF

OXC Server: IL2 FL1 PPL FL1 SEED

Status: Calib. F. Calib. C.

After.

/svn/FLASH/LbSync/LbSync_FLASH_MAIN.xml FLASH.SYNC/LASER.LOCK.EXP/FLASH1.PPL1.OSC1/

FLASH. LbSync Overview: FLASH

Free-Electron Laser FLASH

MLO1 Active Locked

Channel	Jitter	Level
217 MHz	1.352 ps	5.385 %
1517 MHz	17.74 fs	82.36 %

MLO2 Active Locked

Channel	Jitter	Level
217 MHz	836.7 ps	0.011 %
1517 MHz	1.78E fs	0.027 %

FSD 163.19 mW

FLASH: Stabilized Fiber Links

Delay [ps]	Slot /LSU	Lock	Tuning	Jitter [fs]	Piezo [V]	Drift [ps]	Power [mW]
1200.0	7.0	Green	Green	0.29	4.4	103.8	5.71
1020.0	4.3	Green	Green	0.40	-21.7	99.3	5.67
3527.0	7.3	Green	Green	0.33	37.8	351.6	3.68
10.0		Green	Green	0.47	-46.9	2750.6	7.96
10.3		Green	Green	0.75	-47.6	384.5	10.82
4.2		Green	Green	0.65	-33.0	620.4	10.26
4.0		Green	Green	0.21	0.1	1070.3	15.99

Endstations

Station	Jitter [fs]	Status
FLASH.IL1.OSC		Green
FLASH.IL2.OSC	10.54	Green
FLASH.IL3.OSC		Offline
BAM.1UBC2		Green
BAM.3DBC2	27.05	Green
BAM.4DBC3	20.81	Green
FLASH1.SEED	23.44	Green
FLASH1.PPL1.OSC1	57.78	Green
FLASH1.PPL1.OSC2		Green
FLASH1.THZ.OSC		Green
FLASH2.PPL1.OSC1	5.06	Green
FLASH2.PPL1.OSC2		Green
FLASH2.THZ.Streak		Offline
FLASH3.FWD.OSC		Green

RF-MO REF-M-OPT LSU LDD PDUs FREDs Crates Climate System

Thanks.